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Advancing Breast Cancer Detection Through Thermal Imaging and Machine Learning: A Comprehensive Review of Techniques and Applications

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Abstract – *Breast thermography proves to be an evolving diagnostic support method that uses infrared imaging for vascular and metabolic change detection in breast cancer evaluations. This paper conducts an extensive analysis of thermographic imaging progress along with AI-based and ML-based diagnostic enhancement strategies. People conducting comparative studies find that thermography demonstrates utility as a support tool while AI-based convolutional neural networks (CNNs) reach a sensitivity level of 97% in specific applications. The study analyzes two main analysis methods which involve segmentation through K-means clustering and classification through kNN algorithms while evaluating results through combination of fuzzy logic with histogram analysis techniques. The combination of Pennes heat equation with genetic algorithms and finite element methods using simulation techniques delivers useful understanding about tumor dimension and metabolism metrics. Thermography shows potential for clinical use because of its ability to work together with conventional diagnosis methods despite its known temperature-sensitivity and imaging difficulty in dense breasts. Additional research needs to prioritize thermography optimization since this non-invasive approach provides a radiation-free method for detecting breast cancer at its earliest stage.*

Keywords- *ANN, CNN, Fuzzy Logic, Genetic Algorithms, K-Means Clustering, kNN, Machine Learning (ML), SVM*

INTRODUCTION

Breast cancer functions as one of the most occurring malignancies among female patients throughout the global community while producing notable death rates and disease severity. The prompt diagnosis of breast cancer at an early stage proves essential for better outcome and survival statistics of patients. Medical diagnosis of breast cancer primarily depends on mammography alongside ultrasound and magnetic resonance imaging (MRI) assessment methods. These methods have specific boundaries when applied to dense breast tissue cases along with individuals who cannot receive treatment with ionizing radiation. The demanding situation has emerged for finding diagnostic alternatives that are non-invasive while being safe and effective to traditional methods.

Breast thermography provides increased prominence because it measures breast temperature distributions through infra-red imaging analysis. The method detects thermal patterns from vascular and metabolic breast tissue alterations that suggest abnormal development including tumors. Frequent screening needs prompt women toward thermography since it operates without ionizing radiation while providing beneficial options for both dense-breasted and inheritable cancer risk individuals.

Thermography remains an unestablished scanning technique that medical professionals have not accepted for independent disease detection. Breast thermography displays some effectiveness in detecting early breast cancer however its ability to detect cancer and the temperature fluctuations both depend on environmental conditions and individual patient characteristics as well as on benign tissue thermal signatures that may mimic those of cancer. Researchers have introduced different advanced methods that work to enhance the accuracy and reliability of thermographic imaging systems.

The diagnostic ability of breast thermography receives improved capabilities through recent studies that combine artificial intelligence (AI) with machine learning (ML) techniques. These modern technologies allow the assessment of extensive datasets to extract delicate thermal information which standard evaluation techniques cannot detect. Thermographic images receive high sensitivity and specificity results in their classification and identification of malignancies through the use of artificial neural networks (ANNs) and support vector machines (SVM) as well as deep learning models including convolutional neural networks (CNNs).

Research investigators have developed the analysis of thermographic assessments by incorporating K-means clustering segmentation and statistical methods together with feature extraction algorithms. The conjunction of AI and ML models together with these methodologies enables better malignant tumor diagnosis specifically in situations where standard image interpretations face challenges. Using Pennes heat equation and finite element models offers researchers the chance to estimate breast cancer parameters involving tumor sizes along with depths and metabolic activity through simulation-based approaches.

The research targets an analysis of breast thermographic progress while measuring its capabilities against current assessment solutions such as mammography, ultrasound, and PET-CT scanning methods. Through examination of significant research about thermography collaboration with AI and machine learning this paper explores both the advantages and restrictions within thermography before proposing future study directions to evaluate its role as a complementary breast cancer screening method.

LITERATURE REVIEW

Researchers worldwide give high importance to breast thermography as a lesion identification technique during recent years. Research and early breast lesion detection benefit heavily from this technique even though it does not replace existing methods according to literature analysis.

The research by [1] provided a mathematical evaluation between mammography accuracy and breast thermographic accuracy. The authors examined 132 Iranian women from age 24 to 75 who visited the Tehran Cancer Institute for their analysis. The researchers employed both risk assessment through the Marseille system and specific image analysis and thermal variations to classify the obtained thermograms. The authors obtained thermographic images at 21°C room temperature before repeating the process after performing an ice test. Mammography showed better accuracy rates by detecting 76% of lesions according to their results. The authors state that their study limitation derives from the restricted sample size and problematic examination subject matter for thermographic analysis although they find a 69.7% accuracy rate.

Research in [2] evaluates the full body outcomes obtained by PET and breast thermography while performing a joint analysis on these data sets. The authors conducted K-means Clustering analysis on false color thermograms to segment temperature profiles as well as obtained statistical characteristics and breast histograms to determine thermal symmetry. The researchers conducted abnormal mass segmentation within the PET image through MIMICS software. The researchers determined that finding an asymmetric temperature distribution in a thermogram provides an approach for detecting breast cancer.

A thermographic assessment using 92 biopsy-recommended patients was performed by researchers described in [3]. The researchers developed three different scores through which one was produced with risk factor criteria while another depended on clinical patient information and the last score stemmed from artificial neural network analysis. Through their analysis they found 58 of the 60 diagnosed malignant lesions with 97% sensitivity and 44% specificity and 82% negative prediction rate. Their research showed that infrared thermography proves useful when using mammography and ultrasound to detect breast alterations especially for patients with dense breast tissue.

The analysis of thermograms for abnormal detections includes measurements of breast thermal asymmetry by comparing left and right breast characteristics since both breasts should normally match. The researchers in [4] developed a pair of pattern classification approaches through the combination of the k-means unsupervised learning algorithm with the kNN supervised learning method after conducting feature extraction. The authors established that assessing breast asymmetry requires the application of feature extraction techniques as a productive research method.

Research analyzing the technique through independent component analysis for automatic breast cancer detection exists in various publications including [5]. Their research utilized breast thermograms obtained from a public database which they displayed in rainbow color scale. The researchers applied YCbCr color space to segment manually the region of interest and conducted principal component analysis and Otsu algorithm based binarization to isolate pre-diagnosed malignant tissue areas in thermograms.

The authors of [6] demonstrate statistical image analysis of thermograms through a study of histogram features and average and standard deviation calculation. The analysis technique employs image moment calculations to examine the left-right breast temperature pattern by cross-co-occurrence analysis to collect data about the measured features including symmetry, homogeneity, contrast and energy distribution. A classification process occurs through fuzzy logic after processing the thermogram information. Melanoma periods measured in 150 test cases achieved an 80% success rate in implementation.

The succeeding step after confirming breast thermography's lesion detection ability should focus on measuring the lesion parameters. The authors discuss in [7] a method to address the issue that involves modeling thermograms structurally with tumor-specific heat generation along with size and location characteristics. The Pennes biological heat equation received its solution followed by creation of a genetic algorithm for tumor parameterization. The researchers applied the finite element method to generate simulation data for both data sets and gradient matrices.

The worldwide demographics indicate cancer stands as the second leading cause of death resulting in 9.6 million mortalities globally during 2018. Research findings indicate that worldwide cancer produces fatalities at a rate of one in six among total deaths. Over 70% of all deaths occurring in underdeveloped together with medium-developed nations result from cancer [8]. Breast cancer together with lung and colon cancer represent 50% of all recorded cancer instances in female patients. The occurrence of breast cancer represents 30 percent of the newly diagnosed cancer cases which affect women [9].

The authors in [10] extracted breast cancer cell image features through Image J while implementing the Artificial Neural Network (ANN) algorithm. The research enabled the correct identification of breast cancer cell pictures through a 90% success rate. These investigations of early detection for this widespread condition always prove vital. The analysis of machine learning applications toward cancer demonstrates how machine learning methods deliver valuable support during cancer diagnosis and prediction. Machine learning provides tools to examine existing data which reveals necessary relationships and important features of vital information within datasets. This procedure generates computational models which provide proper definition to the available data [10].

The research described in [11] utilized data mining on the Wisconsin breast cancer dataset while performing a performance analysis of different results. The implementation was conducted inside the WEKA study environment using J48 algorithm, Decision tree algorithm, Naive Bayes, Logistic Regression and K-Star methods as example-based classification algorithms. The research conducted showed that the Logistic Regression algorithm outperformed other models by achieving superior accuracy ratings according to [11].

Several machine learning strategies in [12] enabled the prediction of two-year breast cancer recurrence. The ICBC (Iranian Center for Breast Cancer) breast cancer data that resides at the Tehran National Cancer Institute database during 1997-2008 served as the focus of their study. The dataset's missing values were fixed through application of Expectation Maximization algorithm. Three machine learning techniques included Decision Tree (C4.5) and Support Vector Machines (SVM) together with Artificial Neural Networks (ANN). The analysis based on SVM yielded the greatest predictive accuracy with the lowest numerical errors in breast cancer recurrence prediction.

Authors in [13] implemented machine learning approaches to mammogram images for breast cancer diagnosis. The research divided into two sections with a focus on detecting micro-calcification areas in mammogram pictures followed by benign or malignant classification of these regions. The developers created a software application called Breast Cancer Detection System (BCDS) by using the MATLAB platform. The system seeks to identify breast cancer through the combination of four feature extraction strategies and Multilayer Artificial Neural Network along with Support Vector Machines for classification purposes.

The authors in [14] utilized the Wisconsin breast cancer data from UCI Machine Learning Data Repository through WEKA environment to implement Support Vector Machines and Decision Tree (C4.5), Naive Bayes and k-Nearest Neighbor machine learning algorithms. The researchers used accuracy and sensitivity together with specificity and sensitivity parameters during their model classification process. The implementation of Support Vector Machines yielded a best result because it reached 97.13% accuracy with 0.02% error rate.

Support Vector Machines and Random Forest and Bayesian Network were applied to Wisconsin breast cancer data set by the authors in their research on breast cancer early diagnosis as reported in [15]. The research employed Bayesian Network through WEKA software which yielded superior performance based on its sensitivity and precision values. Random Forest obtained the highest result during ROC curve analysis. The model which produced the highest accuracy along with highest specificity and precision was Support Vector Machines.

A research thesis by the authors documented their examination of Wisconsin breast cancer dataset through deep learning methods using Python with performance outcome evaluations. The research employed fully connected neural networks as well as convolution neural networks and simple recurrent neural networks and long short term artificial neural networks and gated recurrent unit neural networks. The authors utilized multiple classical machine learning approaches including Naive Bayes, k-Nearest Neighbor, and Logistic Regression along with Decision Tree in their study. Deep learning system approaches outperform classical machine learning approaches according to the research conclusions. The convolution neural network achieved the maximum accuracy mark of 99.30%.

The authors in [17] performed their thesis study through Python implementation of different machine learning methods on two breast cancer microarray datasets. The target of this research was to utilize machine learning algorithms for generating accurate forecasts while conducting feature selection processes. This research utilized SVM, ANN, k-EYK, Decision Trees, Random Forest, Logistic Regression, Adaboost and Gradient Boosting Machine algorithms to achieve its analysis. Both datasets achieved their best results using SVM methods whereas Decision Trees methods produced their lowest results. All machine learning algorithms that researchers applied within the study obtained comparable results when using the identical feature selection methods on both datasets.

The researchers in [18] used different machine learning approaches to classify breast cancer data in two separate microarray datasets. The objective was to develop precise cancer diagnosis through combining random logistic regression with iterative feature elimination as a feature selection method. The implemented two feature selection approaches yielded superior performance for support vector machines within two breast cancer microarray datasets.

Building tree-based classification models enables researchers in [19] to identify minimal biomarkers from breast cancer patient miRNA expression datasets. The article includes fundamental biomarkers for breast cancer classification while providing details about essential microRNAs for this classification.

In their investigation on the Wisconsin (original) breast cancer dataset, the authors of [20] used ANN and SVM based machine learning techniques in a WEKA environment. Among all the tested algorithms, SVM produced the most optimal results based on various performance evaluations.

The authors from [21] studied automated breast cancer diagnosis through the implementation of machine learning platforms. Medical specialists stated that breast cancer diagnosis success rates improve from using feature-based preprocessing techniques with classification algorithms.

Breast tumor detection research involved 5 machine learning techniques which were implemented using

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MATLAB by the authors of [22]. Through the application of Support Vector Machine (SVM), Logistic Regression (LR), K-Nearest Neighbor (KNN) and Weighted KNN (W-KNN) and Gaussian Naïve Bayes (Gaussian NB) methods the research achieved maximal accuracy of 96.7% utilizing W-KNN. The authors of [23] used W-KNN to achieve 98.9% accuracy in their classifications by first conducting PCA reduction then removing outliers from the data before processing. Deep neural networks were applied by the authors from [24] in their classification research that used multiple activation functions and optimizers. They obtained a 97.94% accuracy value as the result of their ReLU activation function and Adagrad optimizer classification study. Using KNN and Random Forest (RF) methods, the authors of [25] obtained 97.14% accuracy during their algorithmic comparison studies. LR method delivered 93.9% accuracy in the study conducted by the researchers in [26]. The ensemble learning algorithm developed from Bayesian network and Radial Basis Function (RBF) helped the authors reach a 97% accuracy value in their study [27].

Two different classifications were performed by the authors of [28] who achieved success rates of 90.10% and 94.35% when they used default KNN hyperparameters and carried out parameter optimization. Through their created collective learning approach which included KNN and other algorithms like LR, RO, SVM and neural network (NN) the authors of [29] reached 97.9% accuracy in their classification work. The LSTM model by its authors in [30] reached 99.1% accuracy during the completed classification process. KNN and Naïve Bayes (NB) and SVM achieved 90.64%, 84.80%, and 92.98% accuracy in classification results according to [31].

The PSO algorithm with NB classifier enabled the authors in [32] to reach 97.27% accuracy when functioning on their dataset. The paper in [33] carried out classifications using Genetic Algorithms (GA) for feature selection followed by a classification process without feature selection included. The accuracy levels reached 98.24% using LR along with feature selection and 95.1% using KNN after feature selection was mplemented. Through their collective classification algorithm that combined LR and NN the authors of [34] reached 98.5% accuracy working with the 16-element subset obtained from applying feature selection to the dataset.

Both SVM and NN yielded performance metrics of 96.48% and 96.04% during the classification research conducted by authors in [35]. The selected features obtained by [36] led to different accuracy values between 93.2% and 97.2% in their comparative classification study which involved SVM and RO with LR and Decision Tree (DT) and KNN. Among the competitive algorithms the SVM delivered the best performance level at 97.2%. The dataset was classified using multiple algorithms which included LR, NB, KNN and SVM while using different combination of scaling techniques and PCA with resampling strategies according to [37]. The study yielded its best results at 80% accuracy through combining PCA with the LR (Logistic Regression) classifier.

A research investigation by the authors of [38] analyzed how well supervised and semi-supervised machine learning approaches perform in detecting breast cancer. The combination of KNN supervised learning and LR semi-supervised learning generated 98% accuracy as the highest outcome. A comparative analysis was carried out by the authors of [39] who tested six classifiers namely XGBoost, AdaBoost, RO, KA, KNN, and SVM after feature scaling. Results showed that the XGBoost classifier achieved 98.24% accuracy as its maximum performance value. The authors in [40] split their dataset into 75% training and 25% testing allocations and attempted to lower training duration through K-Means clustering techniques on training data. Through SVM on the reduced data set the researchers delivered 98.067% accuracy in their classification task.

Fig. 1 demonstrates breast thermography through infrared imaging by displaying the captured breast tissue temperature distribution. The visual displays thermal differences that suggest abnormalities linked to breast pathology and metabolic and vascular changes. The precision of anomaly detection has improved through applying the advanced segmentation technique K-means clustering for specific region isolation. Early detection of abnormalities becomes a possibility when employing thermographic imaging because it identifies faint thermal fluctuations across the breast.

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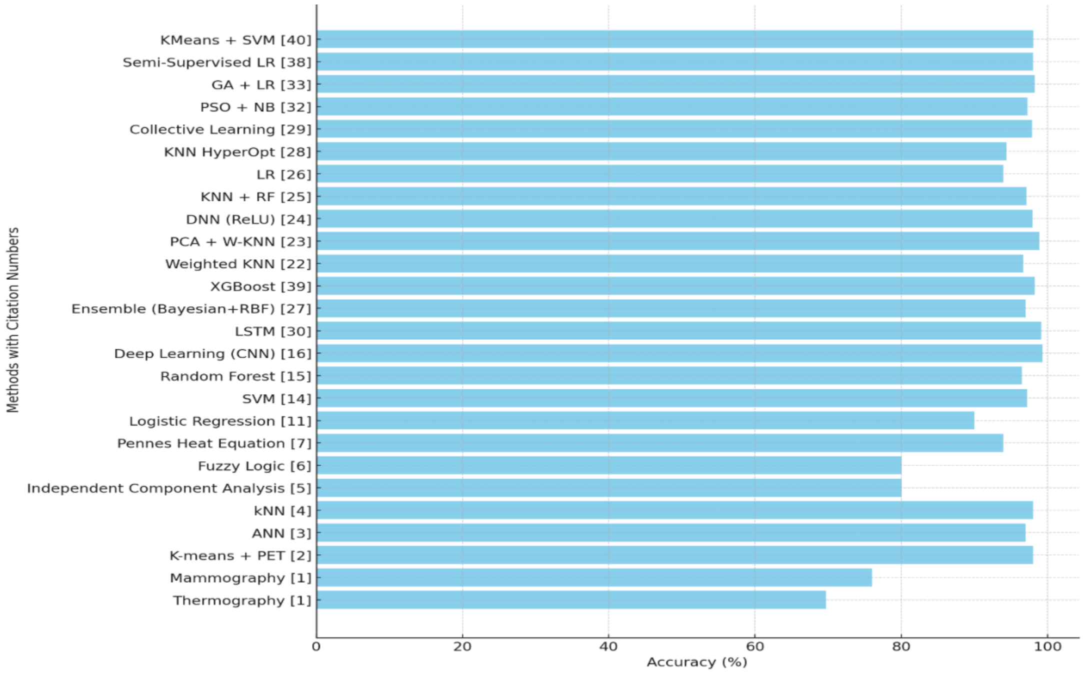

Fig. 1- Accuracy of Various Methods for Breast Cancer Detection

CONCLUSION

Breast thermography provides valuable assistance to standard imaging techniques when identifying breast cancer at its early stages. Breast thermography proves suitable specifically for patients who have dense breasts together with imaging practice concerns due to its non-invasive nature and radiation-free operation which enables AI applications. Modern diagnostic techniques based on sophisticated statistical models with neural networks empower breast thermography to better identify potential issues. Computational methods provide essential tumor information which benefits medical practitioners in their clinical decision-making process. Current research shows insufficient standardized studies utilizing advanced diagnostic approaches which thermal imaging requires to receive widespread approval as an oncological examination method.

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